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Willwood metaquartzite conglomerate in a southwestern portion of the Bighorn Basin, Wyoming

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by

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INTRODUCTION

Objectives

This report presents a study of the metaquartzite cobble conglomerate of the Willwood Formation, late Paleocene (Clarkforkian) to early Eocene (Wasatchian), exposed in a southwestern portion of the Bighorn Basin in northwestern Wyoming. The conglomerate represents a complex system of coalescing alluvial fans which grade into sandstones and mudstones toward the central portion of the Basin (Neasham and Vondra, 1972).

It is the purpose of this investigation to describe the metaquartzite cobble conglomerate and to determine its distribution, provenance, and mode of deposition. Interpretation of this data would contribute toward a more complete understanding of the depositional history of the Willwood Formation and help provide a more comprehensive interpretation of the early Tertiary events in northwestern Wyoming.

Previous Investigation

Fisher (1906) and Loomis (1907) were the first to postulate a fluviatile origin for the "Wasatch" Formation. Their fluviatile hypothesis was later verified by Sinclair and Granger (1911 and 1912) and Granger (1914). Van Houten (1944) discussed the confused usage of the term "Wasatch" and proposed the term Willwood in its place. Further study by Van Houten (1944, 1948, and 1961) provided valuable information regarding the stratigraphy and paleontology of the Willwood and the origin of red-banded strata throughout the Rocky Mountain area.

Van Houten (1944), Neasham (1970), and Neasham and Vondra (1972) demonstrated that the Willwood Formation consists of two major facies; a conglomerate facies along the western margin of the Basin that grades into an interbedded sandstone and mudstone facies towards the center of the Basin. Descriptions of the marginal conglomerate facies indicate that conglomerates off the Beartooth Mountain front are composed of locally derived igneous, metamorphic, and sedimentary detritus (Fisher, 1906; Pierce and Andrews, 1941; Neasham, 1970; Flueckinger, 1971; Bredall, 1971; and Neasham and Vondra, 1972) while conglomerates near Meeteetse in the southwestern portion of the Basin are composed predominantly of metaquartzite cobbles of distant origin (Blackwelder, 1915; Hewett, 1926; Van Houten, 1944; Neasham, 1970; and Neasham and Vondra, 1972). Neasham and Vondra (1972) suggest that the metaquartzite detritus was deposited by a system of braided streams in the distal portion of a large alluvial fan on a piedmont plain.

Antweiler and Love (1967) related the occurrence of gold in the Willwood metaquartzite cobble conglomerate in the Bighorn Basin to that in quartzite detritus from the Harebell Formation (late Cretaceous) and Pinyon Conglomerate (Paleocene) in the Jackson Hole area.

Method of Investigation

The field work for this study was accomplished during the summer of 1971. Conglomerate exposures were mapped on U. S. Geological Survey 7 1/2 minute quadrangle maps and eleven exposures were measured, described, and sampled at localities chosen to accommodate the distribution of outcrops in the area of study (Figure 1).

Clast size and composition counts were made in the field. Each clast larger than large pebble-size (50mm.) found within a randomly chosen, square meter area was broken, and its lithology determined. From 100 to as many as 500 clasts were examined at each locality. The "largest size" method (Pettijohn, 1957) was utilized to obtain an index of clast size. Values for the maximum axes of the twenty largest clasts at each locality were averaged, and the value was used as the maximum clast-size parameter for that locality. The maximum diameter of the ten largest sand grains from interbedded sandstones and sandstone matrix collected from eleven localities was also measured and averaged. The resulting value was used as an index of maximum grain size for each respective sample

The light and heavy mineral fractions of interbedded sandstones and sandstone matrix samples taken from eleven localities (Figure 8) were separated by differential settling through bromoform (specific gravity = 2.90). Non-micaceous heavy minerals were identified and 100 to 200 point counts were made per sample. Quartz, feldspar, and rock fragment ratios for the light mineral fraction were obtained from 200 point counts using a sodium cobaltinitrite staining technique (Reeder and McAllister, 1957).

Thin sections were made of Belt-Series (Precambrian) metaquartzites exposed in eastern Idaho, orthoquartzite and metaquartzite clasts from the Harebell Formation (late Cretaceous) cropping out at Togowotee Pass, Wyoming, and metaquartzite cobbles from the Willwood metaquartzite cobble conglomerate in the area of study. The thin sections were examined and compared for interpretations regarding provenance.

REGIONAL STRATIGRAPHY

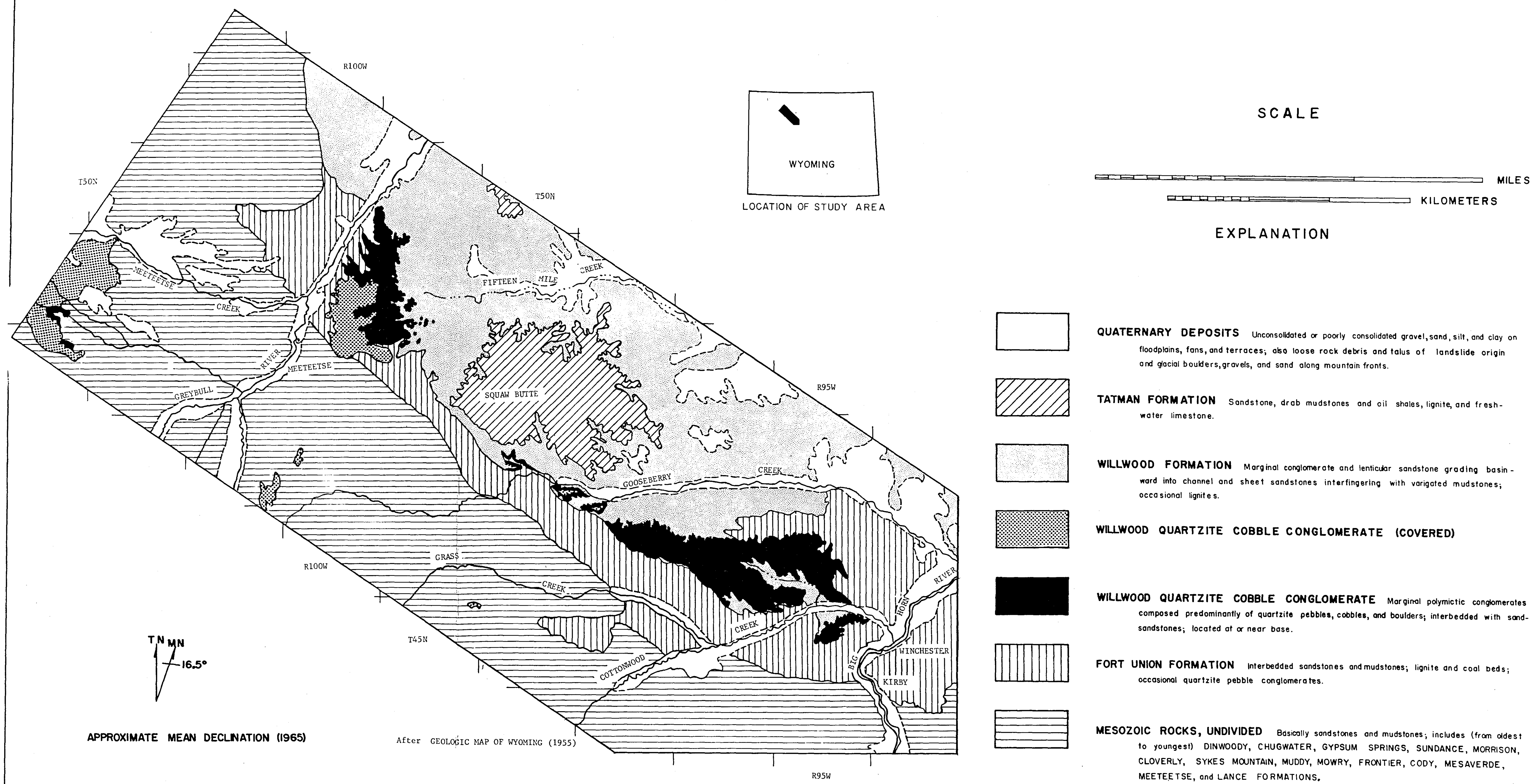
Geologic Setting

The area of investigation occupies nearly 2250 square miles in Park, Washakie, and Hot Springs Counties in the western and southwestern portions of the Bighorn Basin in northwestern Wyoming (Figure 1). The area trends nearly parallel with the southwestern rim of the Basin. The town of Meeteetse is located in the north-central part of the area and the towns of Winchester and Kirby are in the southwestern part. The Greybull River, Fifteen Mile, Gooseberry, Grass, and Cottonwood Creeks flow eastward and are the major tributaries of the Big Horn River which flows northward through the southeastern corner of the area of study.

Although andesites, porphyritic rhyolites, and tuffs had accumulated west of the Basin (near Yellowstone Park) by Paleocene time (Van Houten, 1952), and andesitic, rhyolitic, and dacitic tuffs were deposited from volcanoes in the southern part of the Absaroka Range during the early Eocene (Love, 1960), the major amount of volcanic debris (pyroxene andesite, agglomerate, and fluviatile tuffaceous strata) forming the Absaroka Range was issued during late Eocene and Oligocene time. The Absaroka Range extends from the Beartooth Mountains south into the Wind River Basin, and from Yellowstone Park eastward to form the western rim of the

Figure 1. The distribution of the Willwood metaquartzite cobble conglomerate in the area of study.

THE DISTRIBUTION OF THE WILLWOOD METAQUARTZITE COBBLE CONGLOMERATE IN THE BIGHORN BASIN, WYOMING



Bighorn Basin. The volcanic complex covers the granitic Washakie Range that reached an average elevation of 10,000 feet during Paleocene time and extends from the west end of the Owl Creek Mountains nearly into Jackson Hole (Love, 1937).

The Beartooth (in the northwest) and Owl Creek (along the southern margin) Mountains began to form during the Paleocene and continued to rise until early Eocene. The uplifted Precambrian cores of both mountain ranges along with associated Paleozoic and Mesozoic sediments form the northwestern and southern margins of the Basin.

Stratigraphic Relationships

The marginal conglomerates and interbedded sandstones and mudstones of the Willwood Formation reflect the influx of terrestial sediments into the Bighorn Basin during late Paleocene and early Eocene time. These sediments lie with angular unconformity on Fort Union (Paleocene) deposits or older strata along the front of the Absaroka Range. The Willwood Formation is in turn disconformably overlain by the Absaroka volcanic complex along the western edge of the Basin and interfingers with or is conformably overlain by the Tatman Formation (late early to early middle Eocene, Rohrer and Smith, 1969) in the central portion of the Basin.

The metaquartzite cobble conglomerate occurs in the basal portion of the section and is exposed along the outer margin of Willwood sediments in the southwestern portion of the Basin (Figure 1). The conglomerate forms an angular unconformity with underlying Upper Cretaceous strata along the Absaroka Range and Paleocene Fort Union deposits further basinward (locality 3, Figure 8 ; and Figure 4a). The conglomerate overlies older Willwood sediments towards the central portion of the Basin.

The metaquartzite cobble conglomerate varies in observable thickness from 225 feet in Quartz Gulch (locality 5, Figure 8; and Figure 5a) to about 19 feet along Cottonwood Creek (locality 11, Figure 8) northwest of Winchester. The units interbedded with conglomerate become more abundant and thicker down depositional slope as the conglomerate thins and grades into sand towards the center of the Basin.

PETROGRAPHY

Metaquartzite Cobble Conglomerate

The Willwood metaquartzite cobble conglomerate consists of well-rounded pebble, cobble, and boulders in a sandstone matrix. The clasts are generally pebble- to cobble-size and moderately well-sorted. The coarser material has been abraded into either disk, blade, or spheroid shapes. Almost all of the metaquartzite clasts are pressure marked and some have been completely fractured and re-cemented (Figure 5b).

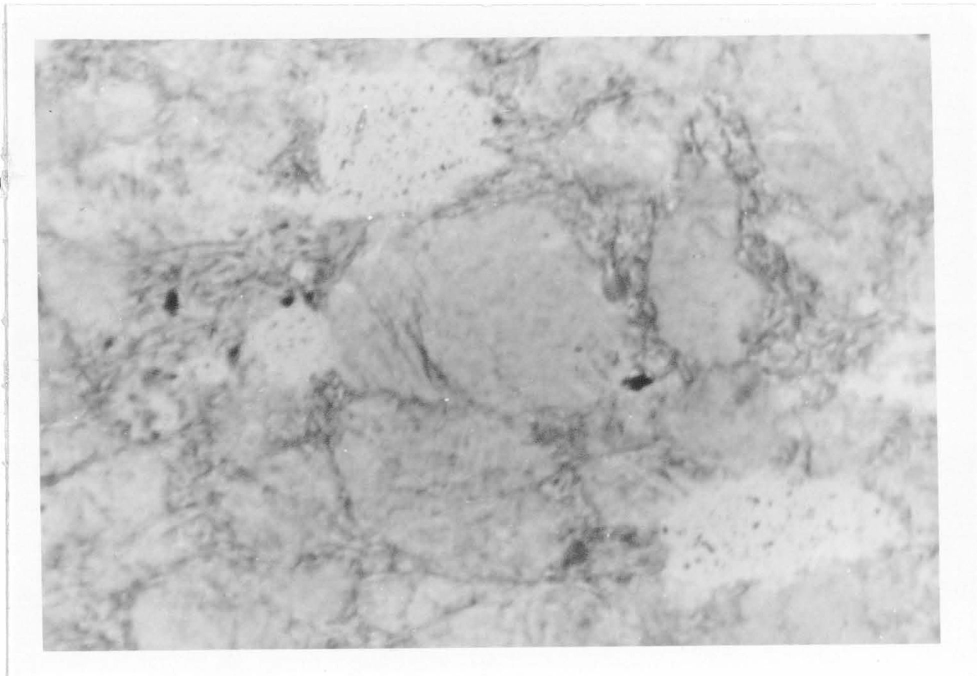
The average maximum diameter of the 20 largest clasts measured at 14 locations is 186.1 mm. with the maximum size (long axis) measured being 687 mm. (locality 5, Figure 8). Figure 9 shows the distribution of metaquartzite conglomerate and the average size (long axis) of the 20 largest clasts from each locality.

Clast lithology counts were made by identifying and counting all clasts larger than large pebble-size (50mm.) within a randomly chosen square meter area (Table 3). Counts indicate that 37.2 % to 76.5 % (averages 65.9 %) of the clasts are composed of fine- to coarse-grained quartzite that varies in color from tan, green, or red to gray, black, and white. Microscopic examination of the thin sections made from randomly sampled quartzite cobbles indicates that approximately 90 % of the cobbles showed stretched quartz

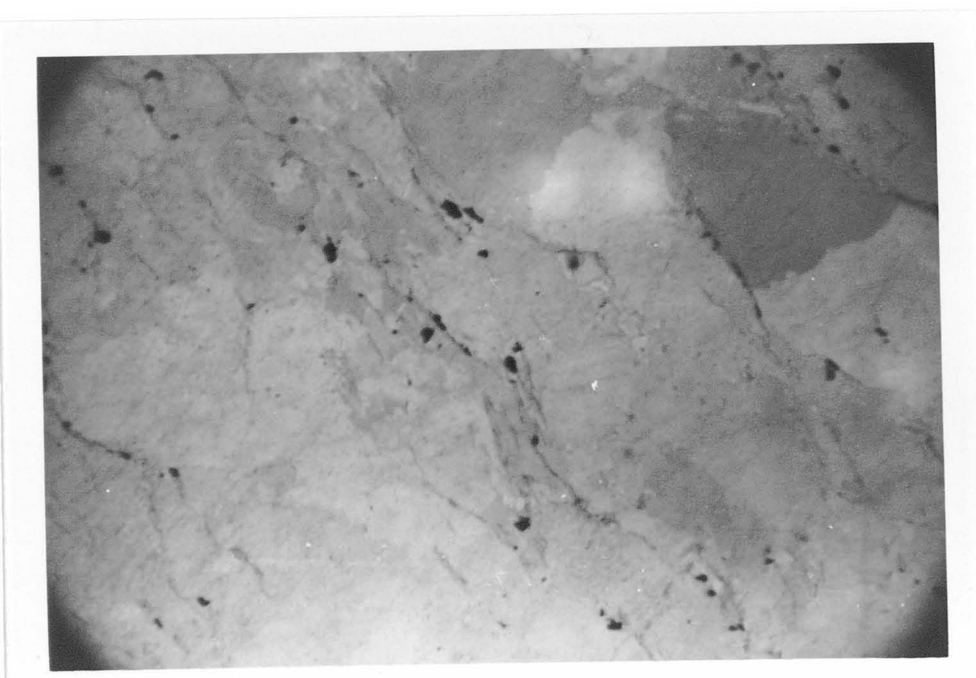
Figure 2. Photographs of thin sections made from Willwood metaquartzite conglomerate cobbles.

a. Coarse-grained metaquartzite cobble from locality 5 (Figure 8).

b. Coarse-grained metaquartzite cobble exhibiting highly elongated quartz grains from locality 2 (Figure 8).



a.



b.

grains with oriented undulatory extinction and sutured boundaries (Figures 2a and 2b). The percent anorthite in plagioclase feldspars from thin sections of quartzite cobbles from the Belt-Series (Precambrian), Harebell Formation (late Cretaceous), and Willwood Formations was determined using the Michel-Levy Method by measuring the maximum extinction angle of albite twins cut normal to (010) (Kerr, 1959, p. 258). Anorthite percentages (Table 1) range from 23.0 % to 45.0 % indicating plagioclase is mainly distributed in the andesine range with five grains distributed in the oligoclase range.

Carbonates (biosparite, microsparite, and micrite) comprise from 3.3 % to 9.6 % (average 5.8 %) and mudstones and siltstones (clayballs) make up from 0.0 % to 23.1 % (average 10.3 %) of all the conglomerate clasts examined. Sandstone (quartzarenite and sublitharenite) clasts are abundant in outcrops on the Thomas Ranch (localities 1 and 2, Figure 8). From 20.7 % to 24.8 % of the clasts examined at these localities were sandstones, while sandstone clasts comprised from 9.1 % to 14.2 % (average 11.2 %) of all the clasts identified at all the other sampling localities in the area of study. The number of chert clasts shows a distribution that is nearly similar to that of sandstone. Chert comprises 13.5 % of the clasts identified at Thomas Ranch (locality 2, Figure 8), and occurs in from 1.6 % to

Table 1. Anorthite percentages in plagioclase grains occurring in metaquartzite cobbles and sandstones

Sample[a]	Average Extinction Angle	Percent Anorthite
1-1	12.5	30.0
5-1[b]	12.5	30.0
5-1[b]	13.0	31.0
5-1[b]	12.0	29.5
5-1[b]	18.5	36.5
5-1[b]	5.0	23.0
5-1	17.0	35.0
5-1	14.0	31.5
5-1	17.0	35.0
5-1	14.5	32.0
5-1	12.0	29.5
5-1	13.0	31.0
5-5	17.0	35.0
5-5	17.0	35.0
5-5	13.5	31.3
5-7	17.5	35.5
5-7	17.5	35.5
5-12	6.0	24.5
5-12	11.5	29.0

[a]Sample designation - First number refers to locality number; second number refers to unit. (Sample 1-1 is the first measured unit at locality 1.

[b]Samples from matrix of conglomerate.

Table 1. (Continued)

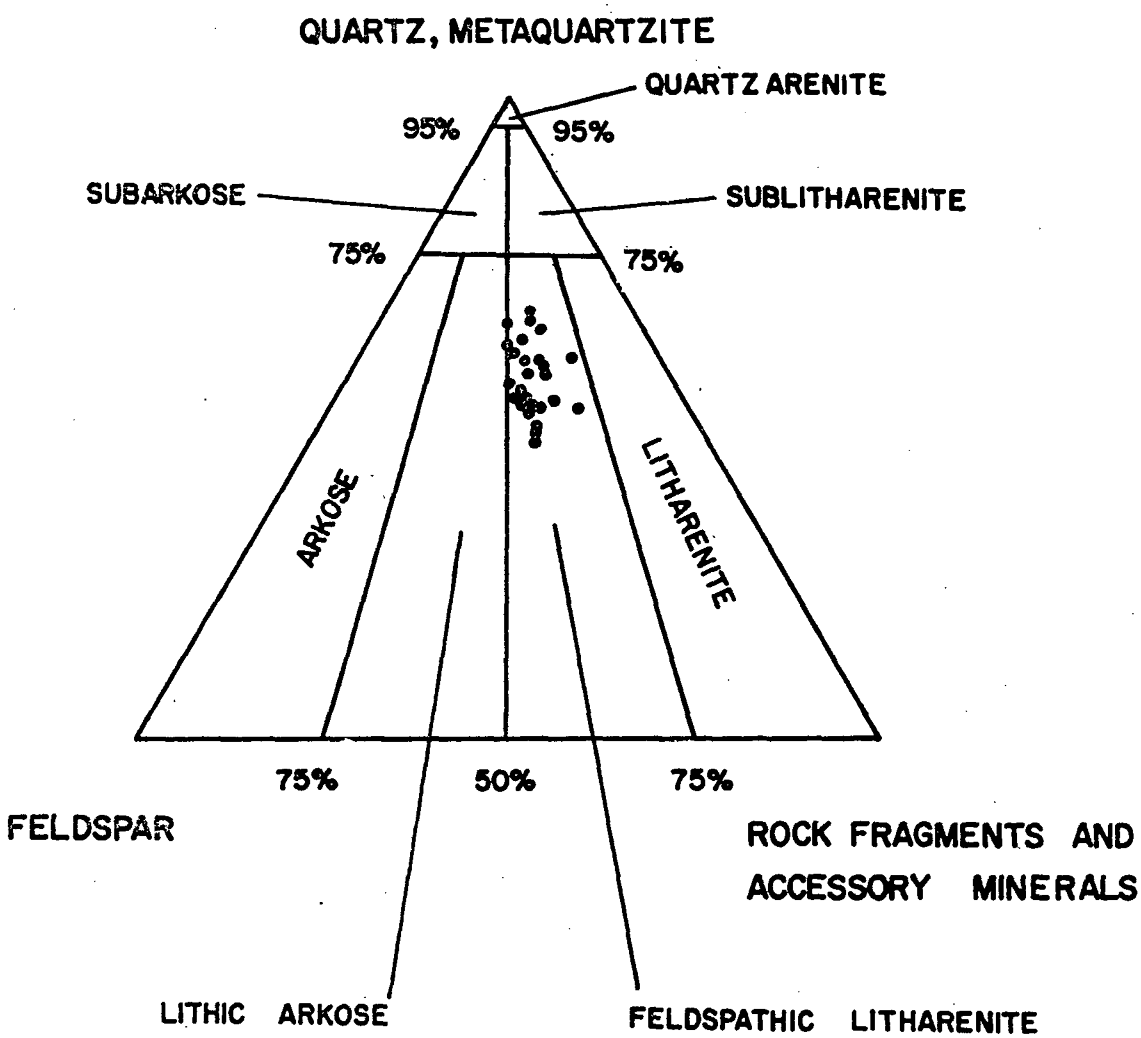
Sample	Average Extinction Angle	Percent Anorthite
5-12	17.5	35.5
5-12	14.5	32.0
5-12	13.5	31.3
13-1[FU]	17.0	35.0
13-1[FU]	19.0	37.0
13-1[FU]	16.0	33.5
13-1[FU]	18.5	36.0
13-1[FU]	21.5	40.5
13-1[FU]	19.0	37.0
13-1[FU]	23.0	43.0
13-1[FU]	15.5	33.0
13-1[FU]	19.0	37.0
13-1[FU]	18.0	36.0
13-1[FU]	25.0	45.0
13-1[FU]	21.5	41.0
13-1[FU]	19.5	38.0

[FU]Fort Union samples.

4.4 % (averages 3.5 %) of all the clasts counted at all other localities in the area of study. Chert clasts made up 44.3 % of the clasts examined in the Fort Union conglomerate near Adam Weiss Peak (sec. 20, T46N, R108W). Volcanic clasts (mostly andesite and rhyolite) occur in Willwood conglomerate exposures from Thomas Ranch to the Quartz Gulch-Gooseberry Creek area (localities 1 through 3, 5, and 6). The amount of volcanic clasts at these localities varied from 0.2 % to 1.6 % of all the clasts examined. Plutonic igneous clasts (porphyritic granite, granite porphyry, and granodiorite) made up 6.8 % and metamorphic clasts (phyllite and schist) provided 1.0% of all the clasts counted at one Thomas Ranch outcrop (locality 2, Figure 8). No plutonic igneous or metamorphic (other than metaquartzite) detritus occurred at any other Willwood conglomerate outcrop locality, nor did any volcanic, plutonic igneous, or metamorphic (other than metaquartzite) clasts occur in the Fort Union conglomerates.

The matrix is similar in composition to the interbedded sandstones. The sandstone matrix is medium- to coarse-grained, sub-angular to well-rounded feldspathic litharenite (Figure 3). Plagioclase feldspars in the in the sandstone matrix have the same range of anorthite percentages as plagioclase feldspar grains found in the thin sections made from metaquartzite cobbles as previously discussed (Table 1).

Figure 3. Classification of sandstones.



COMPOSITION

Sandstone

Grain types counted in sandstone grain mounts made from grains with specific gravity less than bromoform (specific gravity = 2.90) include quartz, metaquartzite, chert, feldspar, carbonate rock fragments, and sandstone rock fragments (Table 2). Quartz is the dominant mineral in all the slides analyzed and comprises from 45.3 % to 66.5 % (average 57.2 %) of the total grains counted. An increase in total percent of quartz grains occurs northeast, east, and particularly southeast from the Quartz Gulch - Gooseberry Creek area (locality 5, Table 2).

The feldspar composition of sandstone grains ranges from 13.8 % to 24.2 % (average 19.0 %). Feldspars were identified with a petrographic microscope after the grains were stained utilizing the sodium cobaltinitrite and hematein staining technique developed by Reeder and McAllister (1957). Plagioclase feldspars comprise from 0.0 % to 6.7 % (average 2.7 %) and orthoclase and microcline make up from 3.7 % to 24.7 % (average 11.8 %) of all the grains counted (Table 2). The marked predominance of potassium feldspars over calcium and sodium feldspars persists at all locations. The number of total feldspar grains in the sandstones decreases northeast, east, and southeast from the Quartz Gulch - Gooseberry Creek area while the total percent of quartz grains increases. The amount of rock fragments and accessory grains also de-

Table 2. Mineralogical composition of sandstones

Slide[a] Number	Feldspars Plagioclase	Orthoclase	Quartz	Rock Fragments and Accessory Minerals
1-1	1.2	20.5	55.2	23.1
1-5	6.3	16.9	50.6	26.2
1-9	7.5	15.2	51.4	25.9
2-1	4.1	14.1	58.3	23.5
2-3	3.6	16.1	56.9	23.4
3-13	3.9	17.3	50.2	28.6
3-18	5.0	18.1	52.7	24.2
4-18	6.1	18.1	45.3	30.5
4-21	2.6	20.1	47.6	29.7
4-25	0.7	16.0	50.7	32.6
4-27	2.9	15.5	51.6	30.0
4-31	1.3	19.3	50.7	28.7
5-1	6.2	14.6	52.1	27.1
5-1	6.1	15.4	53.9	24.6
5-5	2.1	13.5	57.7	26.7
5-7	1.3	15.9	56.9	25.9
6-1	1.1	21.5	52.9	24.5
6-2	2.1	14.3	57.9	25.7
6-3	1.2	15.5	58.3	25.0
7-1	2.6	16.1	59.7	21.6

[a]Slide designation - First number refers to locality number; second number refers to unit number. Slide 1-1 is the first unit measured at locality 1.

Table 2. (Continued)

Slide[a] Number	Feldspars Plagioclase	Orthoclase	Quartz	Rock Fragments and Accessory Minerals
7-1	5.2	15.7	58.6	20.5
7-7	4.2	15.9	59.2	20.7
8-1	2.5	12.1	63.9	21.5
8-1	6.3	12.9	58.2	22.6
8-2	5.8	8.6	66.1	19.5
8-4	3.7	11.1	64.9	20.3
9-1	2.3	17.2	60.7	19.8
9-3	3.1	15.1	61.9	19.9
10-1	6.7	10.9	63.9	18.5
10-3	4.7	9.1	66.5	19.7
10-4	2.7	18.0	62.4	16.9
11-1	3.0	11.8	65.7	19.5

creases down depositional slope from the Quartz Gulch - Gooseberry Creek area toward the northeast, east, and southeast.

Heavy minerals constitute 3.0 % to 5.2 % of the total number of sandstone grains. Table 4 shows the frequency with which the non-micaceous heavy minerals occur in the conglomerate matrix and associated sandstones at each locality. The heavy mineral fraction decreases from about 5.2 % in the Quartz Gulch - Gooseberry Creek area northeast, east, and southeast to about 3.0 % along Cottonwood Creek northwest of Kirby and Winchester (sec. 1, T45N, R94W).

Siltstone

Medium dark grey (N4) and dark yellowish-orange (10YR5/6) siltstones occur interbedded with conglomerate at Hole in the Ground (locality 3, Figure 8). Both siltstones contain considerable amounts of sand-size particles. They are non-fossiliferous and contain small stringers of selenite.

SEDIMENTARY STRUCTURES

Geometry and Structure of the Metaquartzite Cobble Conglomerate

The geometry of the metaquartzite conglomerate and the various sedimentary structures within it are a reflection of the processes operating in the fluviatile system that deposited it. An examination of these properties will contribute useful information concerning the depositional history of the conglomerate unit.

The geometry and extent of the metaquartzite cobble conglomerate is incompletely known because of poor exposure over much of the area (Figure 8). The conglomerate body is locally faulted in the Gooseberry Creek (T46N, R96W and R97W) and Meeteetse (T48 N and T49N, R99W) areas. The conglomerate is exposed south and southeast of the normal fault south of Gooseberry Creek, and is well exposed north and northwest of the normal faults east of Meeteetse. Between these two areas, the down-thrown conglomerate body is partially concealed by younger Willwood, Tatman, and Quaternary sediments (Figure 8).

Conglomerate

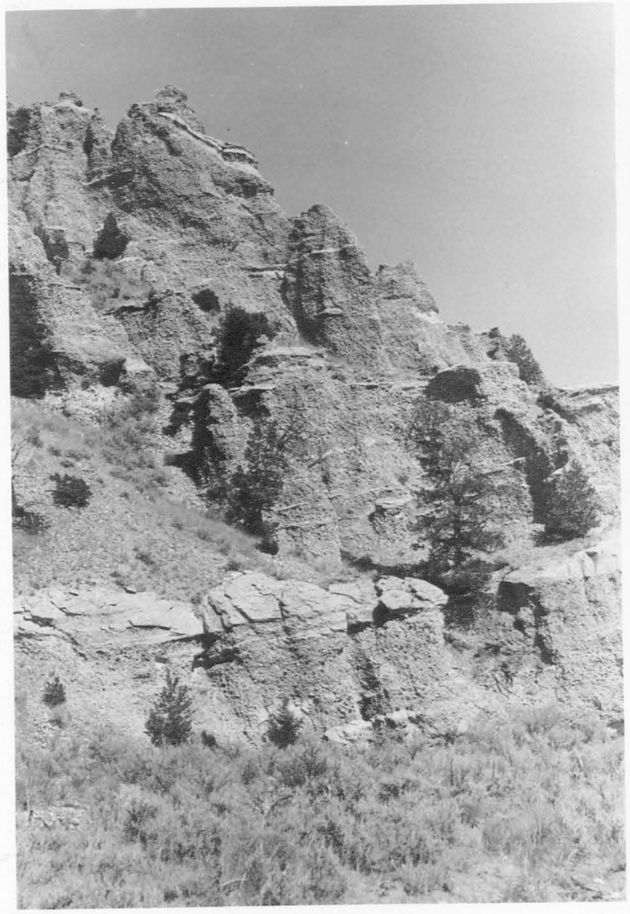
The geometry of conglomerate units vary from tabular bodies interbedded with lenses of sandstone and siltstone (Figure 4) to trough deposits cut into fluviatile sediments

Figure 4. Photographs of tabular bodies and scour channels.

a. Tabular siltstones and sandstones.

b. Sandstone and siltstone filled scour channels in conglomerate.

a.



b.

varying in texture from conglomerate to siltstone. The tabular units range in thickness from 120 feet (locality 5, Figures 5a and 8) to less than 5 feet, and show a general thinning both in a northwestward and southeastward direction from the Quartz Gulch - Gooseberry Creek area (locality 5, Figure 8). The tabular conglomerate bodies display planar basal erosional surfaces. As the tabular conglomerate bodies thin they become interbedded with progressively more numerous sandstones and siltstones. Basinward, the conglomerate occurs only in isolated stringers and localized lenses. The entire conglomerate body is characterized by a complex of scour channels (Figure 4b). The conglomerate-filled scour channels are usually filled with pebble- and cobble-size detritus. Clast imbrication is relatively uncommon. Along the upstream edge of the conglomerate body, these channels are cut predominantly into conglomerate. Further down depositional dip only isolated channels of conglomerate occur in sandstones. The channels vary in thickness from a few feet to 15 feet and up to 32 feet wide. Widths and depths of channels and mean clast size decrease basinward. In cross-section, channels retain a definite lenticular shape, with a slightly convex-upward upper surface and a pronounced concave-upward lower bonding surface..

Sandstone

The geometry of sandstone bodies associated with the metaquartzite conglomerate varies from lenses and channel fills to tabular units (Figure 4a). Tabular units range up to 45 feet in thickness (locality 2, Figure 8; and Figure 5a) and contain tree molds from 35-50 cm. in diameter (Figure 5b). Tabular bodies become thicker and more numerous near the upper and lateral margins of the conglomerate unit. The tabular sandstone units are very discontinuous and are usually traceable along depositional strike for up to 3000 feet (near Gooseberry Creek, locality 5,Figure 8) with 500 to 1500 feet the most common.

Sandstone channel fills occur both in sandstone and in conglomerate. Fills in sandstone are lenticular in cross-section with poorly defined upper and lower contacts due to the similar composition of the fill and the stream bed. Sandstone filled scour channels usually vary in thickness from 1 to 2 feet and extend laterally from 10 to 30 feet. One scour channel was observed at the Quartz Gulch - Gooseberry Creek area (locality 5, Figure 8) that has a thickness of 3 feet and extends laterally for 50 feet.

Siltstone

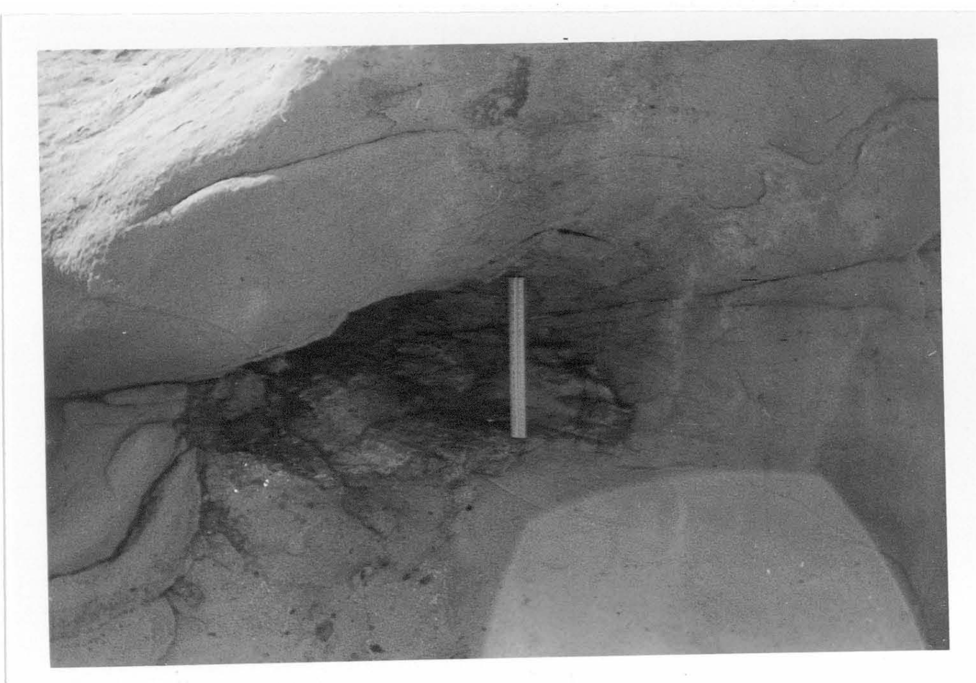
Siltstones are usually associated with tabular sandstone units. Siltstone units grade into tabular sandstones both laterally and up depositional slope. Thicknesses exist up to 45 feet near Gooseberry Creek (locality 5, Figure 8; and

Figure 5. Photographs of sheet sands with enclosed tree molds.

a. Tabular sheet sands above the Willwood conglomerate at Thomas Ranch.

b. Tree molds in the sheet sands at Thomas Ranch.

a.



b.

Figure 6. Photographs of tabular conglomerate, sandstone, and siltstone units, and fractured and recemented quartzite clasts.

a. Tabular conglomerate, sandstone, and siltstone units at Gooseberry Creek.

b. Fractured and recemented quartzite clasts from Thomas Ranch.

a.

b.

Figure 6 a). Poor exposures limited the measureable lateral extent of the siltstone units to approximately 400 feet.

Cross-Stratification

Large-scale trough cross-stratification is the most common type of cross-stratification in tabular and channel-filled sandstones and conglomerates. It is comprised of interfering, grouped sets, large in scale, and underlain by a scoop-shaped erosional surface (Figure 7a). When exposed, the sets exhibit curved, nearly symmetrical cross-strata which are discordant with the surface beneath the set (Pi-type of Allen, 1963). Allen (1963) explains that they are formed by response to cutting and filling of a channel under water by the migration of trains of large-scale asymmetrical ripples with pronounced curved crests. Harms and Fahnestock (1965) believe that trough cross-stratification forms in sand-size material when the energy of the transporting medium has reached the upper part of the low-flow regime, and a relatively high-flow regime must be attained for the formation of similar cross-stratification in gravel-size material.

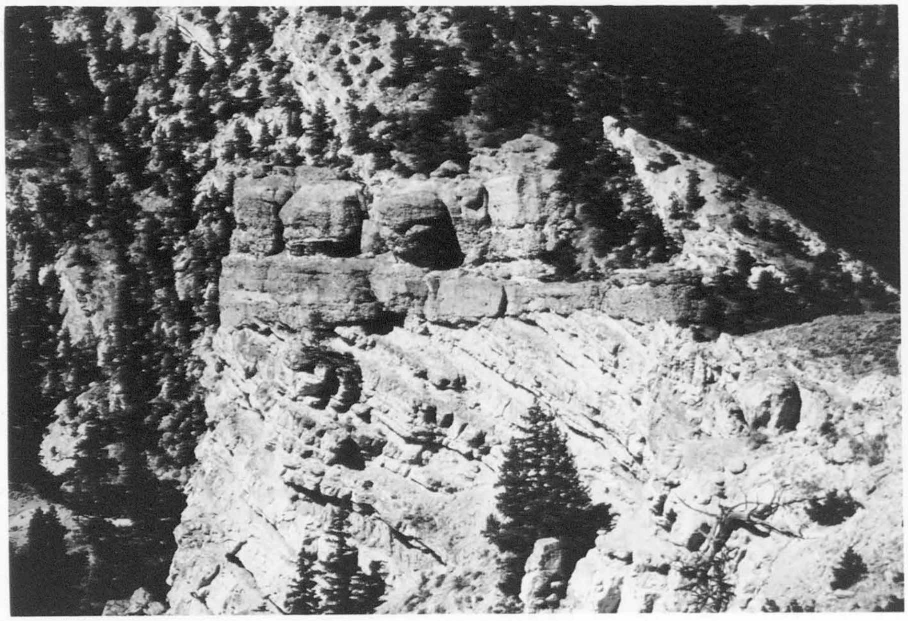
The conglomerates and associated sandstones in the area show three principal types of large-scale tabular cross-stratification. Cross-stratification composed of solitary sets (lithologically homogeneous) with a non-erosional lower surface (Alpha-type of Allen, 1963) occurs in less than 5 %

Figure 7. Structural relationships and primary structure at Hole in the Ground.

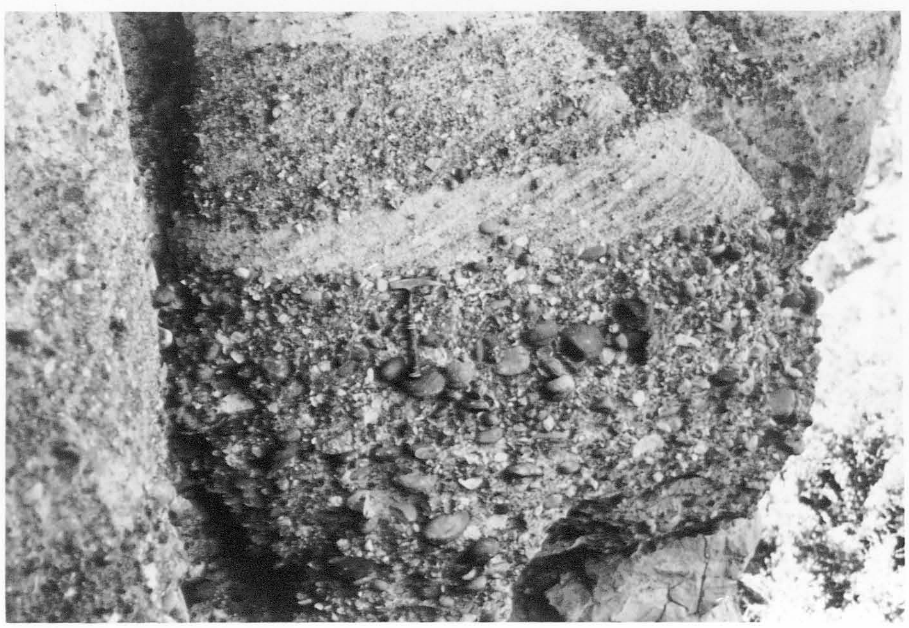
a. Willwood metaquartzite cobble conglomerate forms an angular unconformity with the Fort Union Formation (below).

b. Pi-type trough cross-stratification (Allen, 1963).

a.



b.



of the tabular sandstones exposed. Allen (1963) explains that this type of cross-stratification is formed in shallow water by the building of solitary banks with straight or curving leading edges above slip-off faces. Allen (1963) believes that these structures are formed by braided streams. Tabular cross-stratification found in some tabular sandstones and sandstone channel fills is made up of lithologically homogeneous solitary sets with an essentially planar erosional surface. The cross-strata are discordantly related to the lower surface (Beta-type of Allen, 1963). Their construction is attributed to the building of solitary banks in shallow water, as in the "Alpha-type", but under more erosive conditions with more variable flow regimes (Allen, 1963). This type of tabular cross-stratification is present in less than 5 % of the tabular sandstones and sandstone channel fills. Tabular conglomerates exhibit tabular cross-stratification with lithologically homogeneous solitary sets which are bounded beneath by an irregular erosional surface (Gamma-type of Allen, 1963). Allen (1963) attributes their origin to the construction of solitary banks in rapidly changing flow regimes. Harms and Fahnestock (1965) believe that this type of cross-stratification is produced by high gradient, braided, ephemeral streams.

Other Structures

Horizontal stratification is rarely present but occurs in tabular sandstones near the top of the conglomerate unit. The individual cosets in sandstones ranged up to 1.5 inches thick near the top of the unit. The cosets extended laterally for as far as 27 feet before being truncated by younger erosional surfaces. The lower boundary of each coset is erosional, nearly horizontal, and planar or slightly irregular. Harms and Fahnestock (1965) believe that horizontal stratification in sand-size material is the product of plane-bed or low-standing wave transport marking the lower portion of the upper-flow regime.

Although conglomerate and sandstone bodies are cross-stratified, and some tabular sandstone units display horizontal bedding, most tabular conglomerates and many sandstones are unstratified or possess stratification that is so poorly defined that it can not be recognized. In conglomerates, poorly defined stratification usually results from the texture of the clasts. Harms and Fahnestock (1965) explained that material deposited in the upper-flow regime is commonly unstratified due to the high rate of transport and lack of local settling.

Graded bedding occurs in tabular and trough cross-stratified conglomeritic sandstones (Figure 7b). It results from fluctuations in seasonal conditions and shows a decrease in competency of the dispersing agent over an extended period of time (Pettijohn, 1957).

Pebble and cobble imbrication exists in a few of the conglomerate and sandstone units in the area. Imbrication most commonly occurs in the pebbles of cross-stratified and horizontally stratified tabular conglomeritic sandstones (Figure 7b). Pebble and cobble imbrication occurs in tabular cross-stratified conglomerate units and where clasts are deposited parallel to the sides of conglomerate channels. Blissenbach (1954) noted that poor imbrication results when sheetfloods and violent streamfloods transport and deposit pebble- and cobble-size material.

RESULTS OF DATA ANALYSIS

Pebble and Cobble Lithology

Each clast larger than large pebble-size (50 mm.) from within a randomly chosen, square-meter area at eleven localities in the Willwood Formation and two within the Fort Union Formation was broken and its lithology determined. Table 3 lists the amount (in percent) that each lithology contributes to the total composition of clasts at each locality. Quartzites (approximately 90 % metaquartzite) comprise the greatest percentage of clasts at all localities in both the Willwood and Fort Union Formations. The greatest percentage of metaquartzite clasts occurs at Gooseberry Creek (locality 5, Figure 8) and Hole in the Ground (localities 3 and 4, Figure 8).

Carbonate clasts comprise from 9.1 % to 9.6 % of the clasts examined at Thomas Ranch (localities 1 and 2, Figure 8), but over the rest of the area of study, carbonates occur in from 3.3 % to 7.0 % (average 4.4 %). The percent of carbonate clasts decreases, in all down-current directions, away from the Quartz Gulch - Gooseberry Creek area (locality 5, Figure 8). Willwood (except at Thomas Ranch, localities 1 and 2, Figure 8) and Fort Union conglomerates show nearly the same amount of carbonate clasts.

Except for the unusually high amount of sandstone

Figure 8. Graphic sections of the Willwood metaquartzite cobble conglomerate.

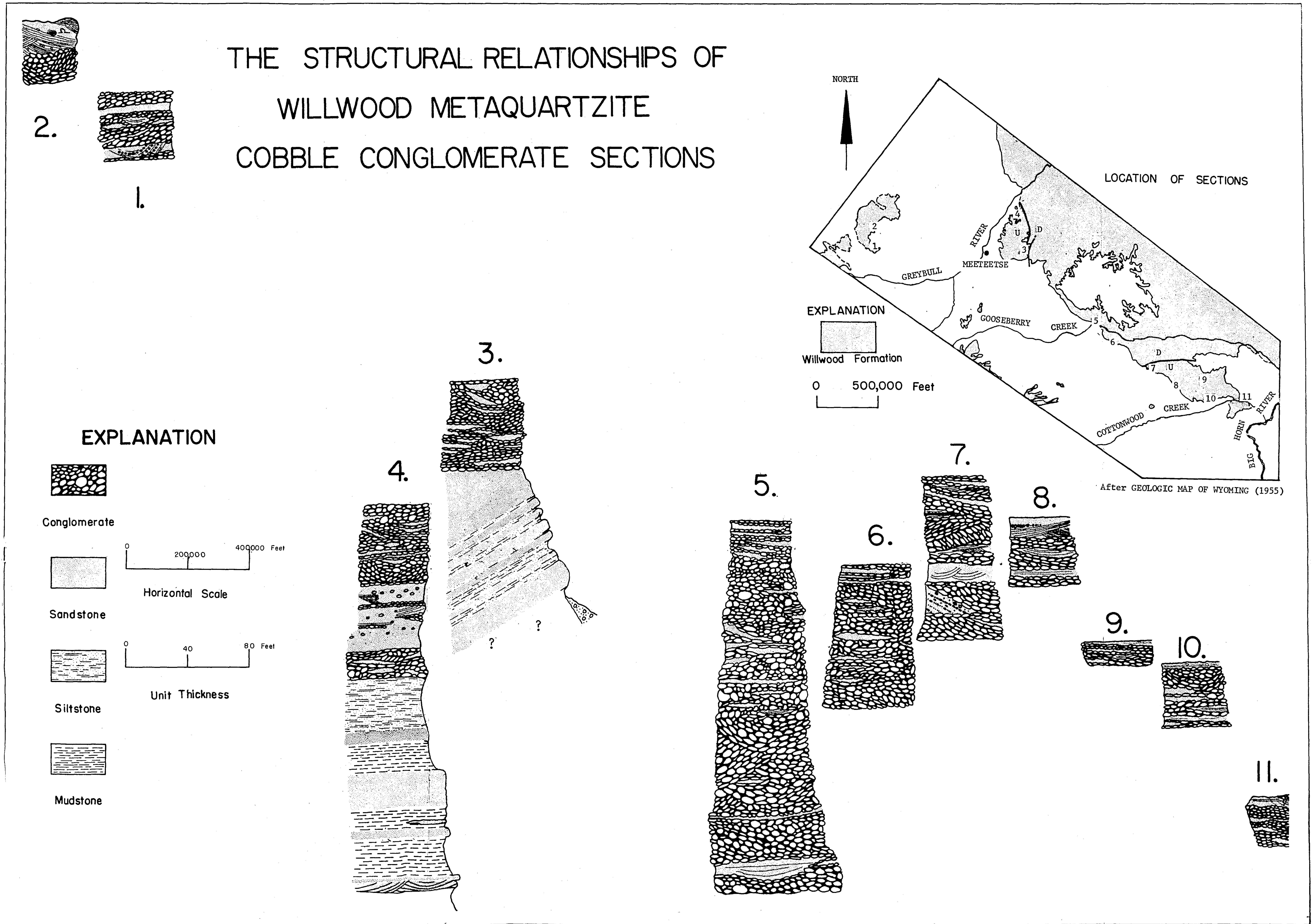
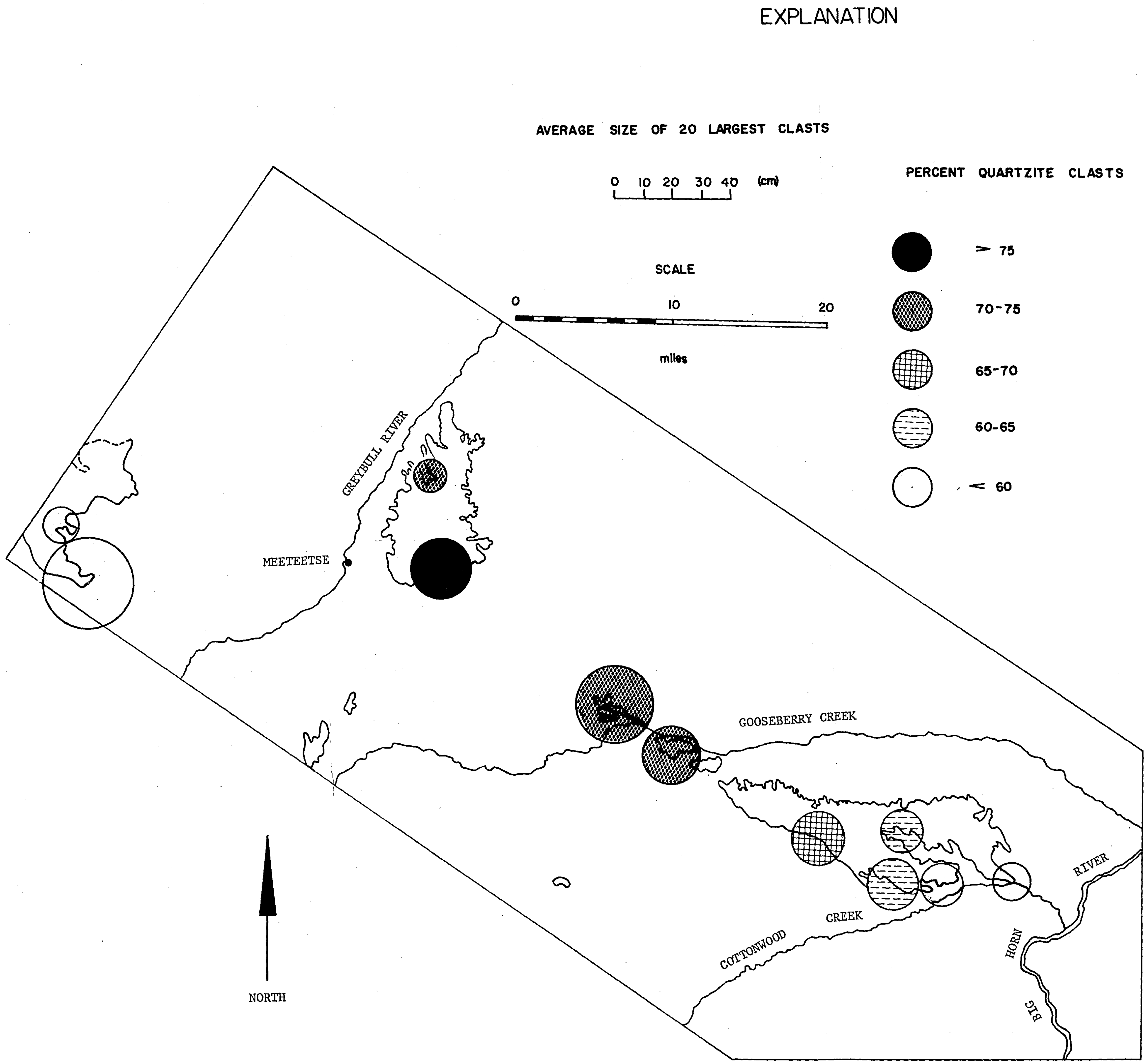

THE STRUCTURAL RELATIONSHIPS OF
WILLWOOD METAQUARTZITE
COBBLE CONGLOMERATE SECTIONS
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
EXPLANATION
Conglomerate
Sandstone
Siltstone
Mudstone
0
200,000
400,000 Feet
Horizontal Scale
0
40
80 Feet
Unit Thickness
NORTH
LOCATION OF SECTIONS
RIVER
GREYBULL
MEETEETSE
GOOSEBERRY
CREEK
COTTONWOOD
CREEK
BIG
HORN
RIVER
EXPLANATION
Willwood Formation
0
500,000 Feet
After GEOLOGIC MAP OF WYOMING (1955)

Figure 9. The distribution of the average maximum clast size and the percent of quartzite clasts at each locality in the area of study.


EXPLANATION
AVERAGE SIZE OF 20 LARGEST CLASTS
0 10 20 30 40 (cm)
PERCENT QUARTZITE CLASTS
> 75
70-75
65-70
60-65
< 60
SCALE
0 10 20
miles
GREYBULL RIVER
MEETEETSE
GOOSEBERRY CREEK
COTTONWOOD CREEK
BIG HORN RIVER
NORTH

(quartzarenite and sublitharenite) clasts at Thomas Ranch (localities 1 and 2), a trend shows the greatest relative amount of sandstone detritus at Quartz Gulch - Gooseberry Creek (locality 5) with the relative abundance decreasing in all down-current directions. Chert occurs with about the same relative consistency at all conglomerate sampling localities, except at Thomas Ranch (localities 1 and 2) no chert was seen among conglomerate clasts at locality 1 while an unusually high amount occurs at locality 2 (Table 3). The amount of chert clasts found in Fort Union conglomerates ranged up to 44.3 % at one location (sec. 32, T53N, R101W).

Volcanic clasts occur in scattered localities (Table 3), but never comprise more than 1.6 % of all the clasts. No volcanic clasts occurred in the Fort Union conglomerates at the localities examined. Plutonic igneous clasts comprised 6.8 % of the total clasts examined at Thomas Ranch (locality 2, Table 3), but did not occur at any other locality in either the Willwood or Fort Union Formation in the area of study. Phyllite and schist clasts comprise 1 % of all the clasts at the same locality (2). Metamorphic clasts (excluding metaquartzite) occur only at locality 2.

Maximum Clast and Quartz Grain Sizes

The distribution of the average length of the maximum diameter (long axis) of the twenty largest clasts found at each locality is shown in Figure 9. A decrease in clast size

Table 3. Summary of total composition of clasts by lithology (in percent)

Location	Quartzite	Carbonate	Sandstone	Siltstone and Mudstone	Chert	Volcanics	Plutonic Igneous	Metamorphics
1	51.6	9.6	24.8	13.1	-	0.9	-	-
2	37.2	9.1	20.7	11.2	13.5	0.5	6.8	1.0
3	73.8	5.2	10.7	5.9	3.1	1.3	-	-
4	76.5	6.0	11.0	3.0	3.5	-	-	-
5L	74.4	8.0	11.0	3.0	3.6	-	-	-
5M	71.1	7.7	14.2	0.0	4.4	1.6	-	-
5U	73.0	7.0	13.5	3.0	3.0	0.5	-	-
6	71.1	6.2	12.2	6.8	3.5	0.2	-	-
7	69.1	5.1	12.1	11.0	2.7	-	-	-
8	68.1	4.1	10.7	14.8	2.3	-	-	-
9	66.2	4.0	10.1	17.7	2.0	-	-	-
10	62.5	3.3	9.0	23.1	2.1	-	-	-
11	62.9	3.4	9.1	23.0	1.6	-	-	-
12	47.7	6.8	0.7	0.5	44.3	-	-	-
13	76.6	4.4	17.6	1.2	-	-	-	-

to the east, northeast, and southeast from the Gooseberry Creek area (locality 5, Figure 8) is evident. The data are unevenly distributed because of poor exposure in the area. This poor distribution of data and their variability inhibits any extensive contouring (Figure 10).

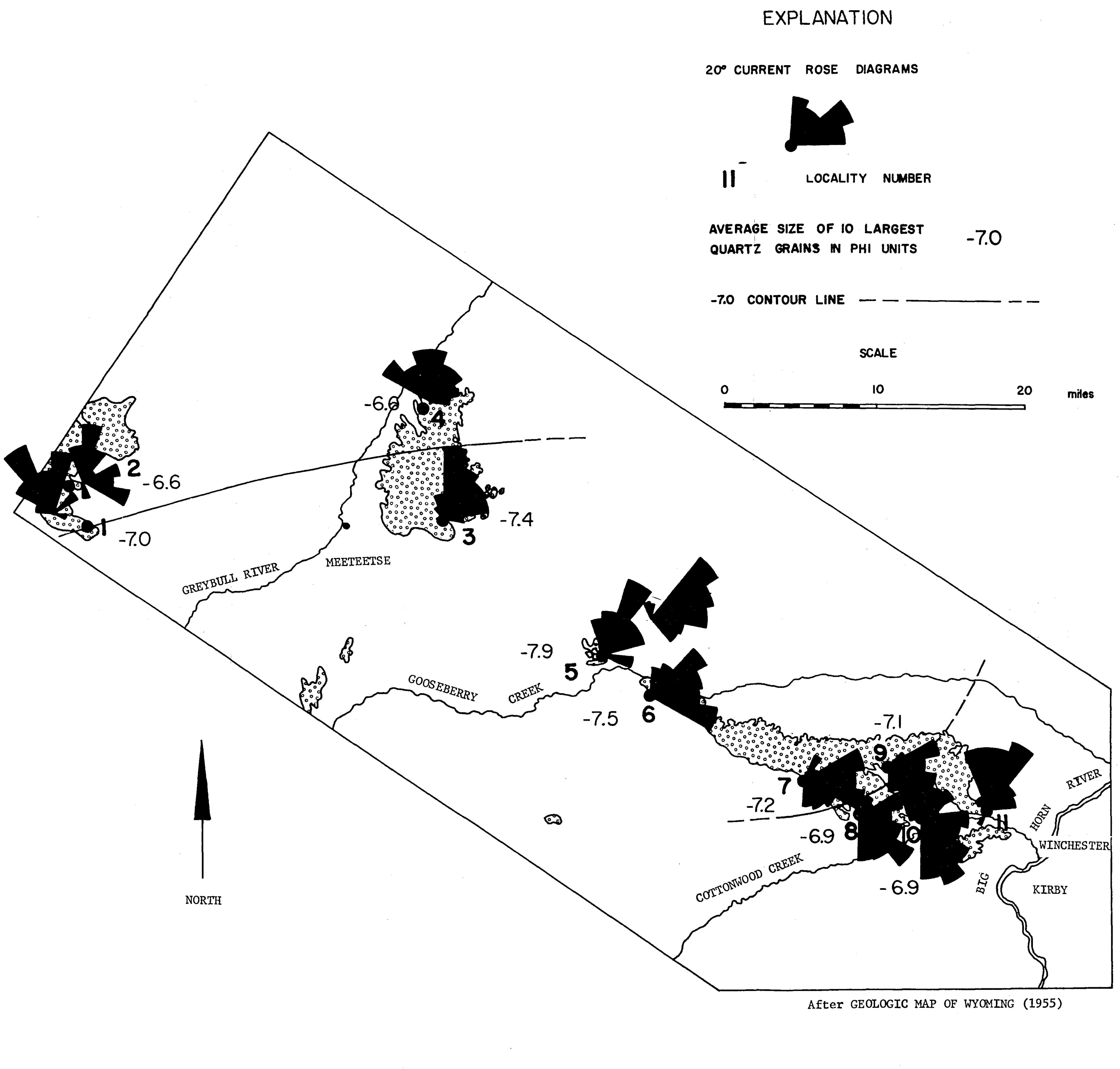
The distribution of the average size, in phi units, of the ten largest quartz grains (long axis) is shown in Figure 10. The data provide incomplete coverage of the area, but the distribution shows a general decrease in size northeast, east, and southeast away from the Gooseberry Creek area.

Paleocurrent Data

A total of 720 paleocurrent measurements were taken on cross-stratification, conglomerate and sandstone channels, and clast imbrication. Current "rose" diagrams were constructed showing the variation in channel azimuths at each locality (Figure 10).

An overall average azimuth of 98.5 degrees indicates that the stream system delivering quartzite detritus into the Bighorn Basin flowed from the west-northwest. The conglomerate in the Meeteetse area (T49N, R99W) has an average azimuth of 40 degrees indicating flow from the southwest, while the area from Gooseberry Creek southeastward to Cottonwood Creek has an average azimuth of 114 degrees suggesting flow from the northwest.

Figure 10. Conglomerate distribution map in the area of study with current rose diagrams and the largest quartz sand grain sizes(in phi units).



After GEOLOGIC MAP OF WYOMING (1955)

Light and Heavy Mineral Composition

The light and heavy mineral composition of the meta-quartzite cobble conglomerate matrix and associated, inter-bedded sandstones was determined after segregation with bromoform (specific gravity = 2.90) (Tables 2 and 4). The amounts of feldspar and rock fragments are each inversely proportional to the amount of quartz in each sandstone sample. The amount of feldspar is greatest in sands from the Thomas Ranch (approximately 20 %), and decreases south-eastward toward Cottonwood Creek (14.8 %). About 30 % of the sand grains near Meeteetse are rock fragments, and this amount decreases to the southeast where at Cottonwood Creek (locality 11) rock fragments comprise 19.5 % of the sand grains. Quartz makes up from 50.2 % to 66.5 % (averages 57.2%) of the sand-size particles in sandstones from the area of study, with a trend showing an increase in quartz grains in all down-flow directions from the Quartz Gulch - Gooseberry Creek area (locality 5, Figure 8).

Heavy minerals comprise about 5.2% of the sand-size fraction in the Quartz Gulch - Gooseberry Creek area (locality 5), and this amount decreases northeast, east, and south-east. The heavy mineral fraction of sands decreases until it comprises 3% of the sand-size sediments in the Cotton-wood Creek (locality 11) area.

Garnet is the most abundant heavy mineral in sands assoc-

Table 4. Heavy mineral frequencies

Heavy Minerals	Mean	Percent Maximum	Minimum
Garnet	36.0	53.9	21.4
Magnetite	10.3	27.3	1.5
Zircon	17.0	29.2	9.0
Limonite	10.6	33.0	0.0
Epidote	7.1	13.8	2.1
Tourmaline	10.6	23.3	2.4
Rutile	0.8	2.4	0.0
Staurolite	2.1	4.8	0.0
Kyanite	2.3	9.3	0.0
Hornblende	3.4	11.9	0.0

iated with the metaquartzite cobble conglomerate, and averages 36.0 % in the area of study (Table 4). Zircon averages 17.0 % and magnetite, limonite, and tourmaline each average slightly more than 10 % of the total heavy mineral composition.

DISCUSSION AND INTERPRETATIONS

Sediment Dispersal and Paleocurrent System

A general decrease in pebble and cobble sizes northeast, east, and southeast from the Quartz Gulch - Gooseberry Creek area indicates a radial dispersal pattern in which coarse detritus was deposited from a westerly and southwesterly direction. Figures 9 and 10 show that sand sizes are consistent with cobble size data except in southern exposures along Cottonwood Creek (localities 10 and 11, Figure 8). This apparent inconsistency may be the result of the sand associated with the pebbles and cobbles being mixed with larger sand transported and deposited later by the same braided stream system after a main channel system changed course and increased competency. The fact that a more southerly source contributed the entire conglomerate body along Cottonwood Creek is doubtful because of: (1) the overall maximum clast size trend throughout the area (Figure 9), and (2) the general similarity in consistency and trend of clast lithology counts at all localities (Table 3).

The Willwood metaquartzite conglomerate represents basin-margin deposition (Neasham and Vondra, 1972). The general decrease in thickness to the southeast, east, and northeast along with paleocurrent data demonstrates that deposition produced a fan-shaped wedge, the apex of which is located west-southwest of the Quartz Gulch - Gooseberry Creek area. Hewett (1926) reports that there were no major rivers northwest of the area of study (T50N and T51N, R99W) during late Paleocene - early Eocene time. As a result, he observed that conglomerate beds in that area are thin and discontinuous and that finer sediments predominate.

Provenance

Lithologic and mineralogic data show that two major source rock lithologies contributed the detritus comprising the Willwood metaquartzite cobble conglomerate: post-Precambrian sedimentary rocks, and Precambrian igneous-metamorphic rock assemblages (Neasham and Vondra, 1972). Hewett (1926) observed such a close correspondence between the Willwood metaquartzite conglomerate and conglomeritic deposits in the underlying Fort Union Formation that he believed there was no doubt the Willwood quartzite conglomerate was largely derived from Fort Union conglomerates. Table 3 indicates that Fort Union conglomerates at the two locations samples show clast lithology counts that are quite similar to those found in the Willwood conglomerate.

Antweiler and Love (1967) studied the quantity, composition, and physical characteristics of placer gold particles found in metaquartzite cobbles and in matrix sands from the Harebell Formation (Upper Cretaceous), the Pinyon

Conglomerate (Paleocene), the Fort Union Formation (Upper Paleocene), and the Willwood Formation (Lower Eocene). They observed that gold occurs in all Cretaceous and Tertiary quartzite bearing conglomerates in northwestern Wyoming and suggested that most of the gold was not derived from adjacent mountains, but rather came from Precambrian and possibly Cambro-Ordivician quartzites from the Targhee Uplift, northwest of the Teton Range. Their studies (utilizing electron beam microprobe analyses) show that a strong and unmistakeable relationship exists between the platinum, palladium, and silver content of the gold from the Bighorn Basin metaquartzite conglomerates and similar contents in the gold from the Harebell Formation and the Pinyon Conglomerate in the Jackson Hole area (Antweiler, 1971, personal communication). On the basis of their gold composition studies, Antweiler and Love (1967) believe that the quartzite debris deposited during early Eocene time in the Bighorn Basin was derived either from the Harebell, Pinyon, and/or Fort Union Formations or it may have been derived directly from the same source as the older conglomerates, or both.

Love and Reed (1968) propose that the source of the metaquartzite debris found in Cretaceous and Tertiary sediment in northwestern Wyoming is the now denudated and buried Targhee Uplift northwest of the Jackson Hole area. Preceding denudation and burial by Tertiary volcanics, at least 15,000 feet of overlying Paleozoic and Mesozoic strata (Love and Reed, 1968) were stripped away before any of the 50 cubic miles of metaquartzite debris deposited in northwest Wyoming was exposed to erosion (Antweiler and Love, 1967).

An estimate of the minimum amount of metaquartzite accounted for by the Willwood metaquartzite conglomerate in the Bighorn Basin can be obtained from the volume of conglomerate exposed therein. Assuming the conglomerate is composed of about 75 % clasts, and about 66 % of the clasts over the entire area are metaquartzite, a minimum of about three cubic miles of metaquartzite debris would be required to meet the needs of the conglomerate outcrops. The maximum amount of metaquartzite deposited in the Basin was calculated on the assumption that the entire southwestern part of the Basin was filled with cobbles and sand forming a large fan-shaped deposit about 350 feet thick along the western margin of the Basin and wedging out along the Greybull River to the north and east in the central portion of the Basin. If 75% of the deposit is composed of clasts, and about 66 % of the clasts are quartzite, an accumulation of sediment of this magnitude would incorporate about 17.3 cubic miles of metaquartzite debris.

Assuming that Fort Union conglomerates extended in a band 20 miles wide and 100 feet thick along a stream system that flowed between the Washakie Range and the Beartooth Mountains from the Yellowstone - Jackson Hole area to the Bighorn Basin, an estimate of the approximate volume of metaquartzite debris incorporated in the conglomerate can be determined. If the conglomerate is composed of 75 % clasts, and about 60 % of the clasts are metaquartzites, about 16.2 cubic miles of metaquartzite debris would be represented by Fort Union conglomerates. This amount would provide enough metaquartzite to fulfill the minimum needs of the Willwood metaquartzite conglomerate (3 cubic miles) but would not provide enough detritus to fill the western side of the Basin to attain a maximum value (17.3 cubic miles).

16.2 cubic miles of metaquartzite debris would theoretically be available from the Fort Union Formation to be redeposited in the Willwood Formation in the Basin, but as can be seen from Fort Union conglomerates in situ, all of the Fort Union conglomerate was not exposed to erosion. It would therefore seem improbable that the Fort Union Formation alone provided all the sediment necessary to account for the volume of metaquartzite debris in the Willwood metaquartzite cobble conglomerate.

Thin sections made from Belt-Series (Precambrian metaquartzites sampled from the Lemhi Range near Patterson, Idaho were examined in attempt to correlate the mineralogical and textural properties of these metaquartzites with the same properties observed in thin sections of the metaquartzite clasts occurring in the Willwood Formation. Even though about 90 % of the thin sections made from Willwood conglomerate clasts exhibit elongated quartz grains with oriented undulatory extinction and sutured boundaries, textural and mineralogical properties differed such that no direct correlation could be made between Willwood clasts and Belt-Series metaquartzites.

Antweiler (1971, personal communication) could not relate the compositional or textural properties of placer gold from metaquartzite conglomerates in the Bighorn Basin or the Jackson Hole area to gold in sediments from the Lemhi Range near Patterson Idaho (east-central Idaho) or the Beaverhead Conglomerate (Upper Cretaceous-Paleocene) from southwestern Montana. Since the only exposures of Belt-Series and Paleozoic metaquartzites that were not buried by Tertiary volcanics are exposed in east-central Idaho (Lemhi Range), about 40 to 60 miles farther west than the proposed location of the Targhee Uplift (as suggested by Love and Reed, 1968), considerable differences in the texture and mineralogy of the metaquartzites would probably occur.

Several grain types are indicative of provenance. Well-rounded and highly spherical quartz grains were probably recycled from Paleozoic and Mesozoic sandstones exposed in the bordering uplands during the early Eocene (Neasham and Vondra, 1972). A large portion of these well-rounded grains were undoubtedly recycled from the 15,000 feet of Paleozoic and Mesozoic strata that were stripped off the rising Targhee Uplift during late Cretaceous time. First cycle, angular quartz, feldspars, and blue-green hornblende suggest a plutonic source near the site of deposition, probably the granitic Washakie Range (Love, 1937), not buried beneath Absaroka volcanic rocks.

Sand- to pebble-size chert particles in the conglomerate could have been derived from several potential Paleozoic sources. The fact that chert particles represent 44.3 % of the clasts in the Fort Union Formation (locality 12, Table 3) illustrates the recycling of predominantly Paleozoic sediment (probably Pennsylvanian Tensleep) as they erode off uplifting mountain ranges (Washakie and Beartooth Ranges). The occurrence of igneous clasts at Thomas Ranch (locality 2, Table 3: and Figure 8) would support the theory that mountain range uplift had proceeded until an igneous core was exposed and dissected.

High grade, highly-rounded, metamorphic garnet comprises about 36.0 % of the heavy mineral fraction of associated sands and matrix. A study of the heavy mineral content of the Pinyon Conglomerate (Lindsey, in Steidtmann, 1971) indicates that it has a garnet content that is nearly similar to that from the Willwood metaquartzite conglomerate. It is therefore probable that the Pinyon Conglomerate was part of the source for the garnet in the Willwood.

The Upper Cretaceous Harebell Formation, the Paleocene Pinyon Conglomerate, and the conglomeritic deposits from the Upper Paleocene Fort Union probably supplied rounded metaquartzite clasts and similar sands to the Willwood conglomerates in the Basin. Carbonate and sandstone clasts and rock fragments from the Willwood metaquartzite conglomerate further emphasize the wide range of Paleozoic and Mesozoic strata which were eroded and which contributed detritus to the Bighorn Basin during late Cretaceous and early Eocene time.

The fact that well-rounded pebbles of rhyolite and andesite occur at 6 localities (Table 3) in the Willwood metaquartzite conglomerate, and were identified by Van Houten (1952) in the Fort Union conglomerates, indicates the presence of volcanic rocks (Paleocene or older) west of the Basin. Since vulcanism began in the southern part of the Absaroka Range during early Eocene (Love, 1960), and in the central and north-central parts of the Range during late Eocene to Oligocene time (Van Houten, 1952), the rhyolite and andesite pebbles from the Fort Union and Willwood Formations were likely issued from volcanoes near the Yellowstone Park area.

Considering the rhyolite and andesite pebbles were deposited with metaquartzite sediments in both Formations, and the volcanic clasts could have originated only from the Yellowstone vicinity, a logical assumption would be that the clasts comprising the Fort Union and Willwood conglomerates were transported from the Yellowstone Park area.

Depositional Environment

The fact that deposition occurred in an alluvial fan environment is evidenced by: a rough semicircular pattern made by paleocurrent directions, the coarseness of the detritus, the decrease in clast size to the northeast, east, and southeast, and the rudely lenticular units which exhibit cross-stratification which is due to the cutting and filling of channels (Denny, 1967; Blissenbach, 1954; Wilson, 1970; Steidtmann, 1971; Eckis, 1928).

A decrease in pebble and cobble size, a general unit thinning, and an increase in the amount of interbedded sand, northeast, east, and southeast from the Quartz Gulch - Gooseberry Creek area (sec. 15, T47N, R98W) indicate a decrease in stream competence down depositional slope in those directions (Lustig, 1963). A general similarity in clast lithology counts along with paleocurrent data and stratigraphic relationships indicate that the Willwood conglomerate was deposited on a broad alluvial fan radiating eastward into the Basin from an area along the western margin of the Basin, west-southwest of the Quartz Gulch - Gooseberry Creek area.

A general absence of fine-grained overbank material and the coarseness of the conglomerates suggest deposition on an alluvial fan (Neasham, 1970). Sediment accumulation in the metaquartzite conglomerate is less rapid than in the Willwood carbonate and mixed igneous and metamorphic conglomerates off the eastern front of the Beartooth Range as suggested by Neasham and Vondra (1972). The greatest portion of the metaquartzite cobble conglomerate was deposited by streams and streamflooding. Streamflood deposits possess scattered clast imbrication and moderately large-scale trough stratification (Blissenbach, 1954). Cross-stratification and imbrication are well developed in stream deposits. Infrequent sheetflood deposition is evidenced by unstructured, tabular conglomerates. Allen (1965) suggests that streamfloods occur when stream channels on the alluvial fan become overloaded. Sheetfloods are formed in response to this clogging when clogged alluvial channels are diverted or over-flooded and the fan surface is covered with a sheet of coarse detritus. Streamflooding and sheetflooding would have occurred intermittently in direct response to periods of heavy rainfall. Well developed stratification, channeling, and interbedded lenticular sandstones and conglomerates are characteristic of a distributary system of braided streams on the lower reaches of an alluvial fan (Blissenbach, 1954; Allen, 1965).

Fossil flora and fauna from the Willwood Formation indicate that the early Eocene sediments accumulated in a warm, humid lowland region, probably not more than 1000 feet above sea level (Van Houten, 1948 and 1952; Neasham and Vondra, 1972). Mackin (1947) states that in general, during early Eocene time, the ranges surrounding the Basin stood not more than 3,000 to 5,000 feet (about half their present height) above the Basin floor and that localized Lower Eocene sedimentation resulted from entrapment in the down-sinking Bighorn Basin rather than from any inherent deficiency in the transporting power of streams.

Transportation of clasts in the Willwood metaquartzite cobble conglomerate from the Jackson Hole and or west Yellowstone area was probably accomplished by the extension of coalescing alluvial fans to form a piedmont plain as suggested by Love and Reed (1968, p. 89) and Neasham and Vondra (1972). Since the volume of detritus on a piedmont plain is constant and remains constant as long as there is no change in the environment, the plain acts as a "conveyor belt" transporting sediments from the source area to the eastern end of an upland adjacent to the western rim of the Bighorn Basin (Denny, 1967). As braided streams carried detritus to the Basin, the decrease in gradient caused deposition in an alluvial fan configuration. The area of study lies in the distal portions of the alluvial fan system which extended into the Bighorn Basin and had its apex approximately 20 miles west-southwest of the Quartz Gulch - Gooseberry Creek area.

CONCLUSIONS

1) Paleocurrent indicators, clast size trends, and clast lithologies indicate that the Willwood metaquartzite cobble conglomerate was transported from a source area west and southwest of the Bighorn Basin, and deposited in an extensive fan-shaped deposit, approximately 75 miles across, in the southwestern portion of the Basin.
2) Clast lithology counts indicate that fine- to coarse-grained quartzite (approximately 90 % of the quartzite cobbles are metamorphosed) constitutes the greatest percentage of the clasts at each locality (37.2 % to 76.5 %, averaging 66.0 %).
3) The absence of a local source of metaquartzite along with paleocurrent directions, clast textural and mineralogical features, heavy mineral compositional comparisons, and gold composition analyses indicate that the detritus was mostly likely recycled from the Pinyon Conglomerate and Harebell Formation in the Jackson Hole area, and the Fort Union Formation in northwestern Wyoming with additional sediment supplied by eroding Mesozoic and Paleozoic strata, and redeposited in the Bighorn Basin in response to late Paleocene - early Eocene Laramide uplift.
4) The general clast size along with characteristic large-scale trough and tabular cross-stratification indicates

the metaquartzite detritus was transported by high-gradient ephemeral braided streams.

5) The probable distance of transport, clast size, and the distribution of the metaquartzite conglomerate suggests that it is a complex fan-shaped deposit located on the distal end of a piedmont plain that extended from the Jackson Hole-Yellowstone area into the Bighorn Basin.

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